

AN INVESTIGATION OF TWENTY-ONE SASKATCHEWAN BALL CLAYS¹

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ABSTRACT

Twenty-one Saskatchewan ball clays have been investigated; the study covers in a general way their chemical, raw, and fired properties. The information presented will no doubt prove of immediate interest to the ball clay trade and especially to the Saskatchewan shippers and exporters.

In general, the more outstanding properties of the clays studied are raw strength, fired color, crack resistance, and rate of vitrification.

Their raw strength is remarkably high, greater than that of any similar clay on the market at the present time. One clay developed the exceptional raw strength, though diluted with 50% potters' flint, of over 1000 lbs. per square inch, a second one 938 lbs., while the average of the eleven highest is 812.8 lbs.; clays of such high strength should prove of interest to the trade where it is desirable to reduce losses in the raw and bisque state.

A number of the clays tested are outstanding as ball clays in that they fire white or nearly so up to and including cone 12, the purity of whiteness being equal to that of white firing china clays.

The porosity and fired volume shrinkage of the Saskatchewan clays corresponds more nearly to those of the English ball clays than do the Tennessee-Kentucky clays as studied by Sestonell.

Introduction

Information concerning the clays of Saskatchewan that fire to a light color has been meager. The existence of these clays has been known for many years. Dr. Bell³ made mention of them in his report on the coal seams of the Dirt Hills (Sask.). It is not likely that Dr. Bell attached any importance to the clays.

The first test of the Saskatchewan light clays was conducted in 1907 by Edward Orton, Jr., on twenty-seven samples of clay collected from the Dirt Hills by Daniel Diver.⁴

The first official report of these clays was given by Ries and Keele.⁵ This was followed in 1918 by a more detailed report by N. B. Davis.⁶

The work of Davis awakened a ceramic interest in Saskatchewan and this led to the establishment of the Ceramic Department at the Saskatche-

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² Prof. Ceramic Eng., Univ. of Sask., Saskatoon, Sask.

³ Dr. Bell, Report of Progress, Geological Surv. Can., 1873-74.

⁴ Prospector.

⁵ Ries and Keele, The Clay and Shale Deposits of the Western Provinces, 1912.

⁶ N. B. Davis, Report on the Clay Resources of Southern Sask. Dept. of Mines, Canada.

wan University in coöperation with the Department of Railways, Labour, and Industries of the Provincial Government, the activities to be not wholly academic but also to conduct surveys and research work on the clays of the province.

A study of twenty-one Saskatchewan ball clays was one of the surveys made.

The field collection of the samples and much of the research was completed in 1924. All samples and records were destroyed in the disastrous fire at the University in 1925.

The Laboratory Investigation

Preparation of Samples

Care was used to procure an average sample of each clay at the deposit. On arrival at the laboratory they were allowed to room dry. One hundred pounds of each were crushed in rolls, slowly fed into a tank of water, and soaked for 24 hours, then thoroughly blunged, screened through a 100-mesh

Tyler brass screen, allowed to settle, the excess water siphoned off, the slip thoroughly stirred and forced into a filter press by compressed air. The filter-pressed cakes of each were dried to a point where they could be re-crushed and dry screened through 8-mesh, the batch thoroughly dry mixed, water added, and the mass wedged on plaster and packed into large stone-ware jars, covered, and allowed to age for forty-eight hours. After re-wedging all trial pieces were prepared in as short a time as possible, the same assistant making the same trial pieces from clay to clay, thus avoiding insofar as possible any variations. To further avoid chances of error



FIG. 1.

there were made ten trial pieces for each test or measurement and the average taken as the final figure.

Tests Made

The tests made were as follows:

- (1) *Chemical*: Six clays were selected for this.
- (2) *Elutriation*: The percentage and size of particles in each sample finer than 20-mesh were determined. The apparatus used was patterned after Schultz, though the construction and operation followed Krehbiel.⁷
- (3) *Hydrogen-Ion Concentrations*: The values for the several clays were determined in a La-Motte roulette comparator. A quantity of

⁷ Trans. Amer. Ceram. Soc., 9, 173-85 (1904).

ground clay was placed in a quart fruit sealer with sufficient distilled water to make a thin slip, the sealer placed in the frame of a ball mill in such a position that at each revolution of the mill the clay slip was thrown or splashed from end to end of the sealer for two hours. The clay was then allowed to settle and the determinations made.

(4) *Water of Plasticity:* The samples were hand pressed in a steel mold, 11 by 1 by 1 inch, and cut into trials, $2\frac{1}{2}$ by 1 by 1 inch. They were weighed immediately and, after drying at 110°C , cooled in a desiccator.

(5) *Per cent of Shrinkage and Pore Water:* These were determined by the Standard Method of the AMERICAN CERAMIC SOCIETY.



FIG. 2.

The wet and dry volumes were taken of the trial pieces used in obtaining the water of plasticity, thus it was only necessary to apply the following formulas:

$$\text{Shrinkage water} = i_s = \frac{V_p - V_d}{W_d} \times 100$$

Where i_s = the percentage of shrinkage water

V_p = the plastic volume in cu. cm.

V_d = the dry volume in cu. cm.

W_d = the dry weight in grams

Pore water = $i_p = T - i_s$

Where i_p = the percentage pore water

T = the percentage water of plasticity

(6) *Volume Drying Shrinkage:* The volume drying shrinkage was determined on trial pieces, $1\frac{1}{8}$ by $1\frac{1}{8}$ by $1\frac{1}{8}$ inches. The freshly made trials were placed at once into a kerosene bath, their green volume men-

tured in a Schurecht overflow volumeter, room dried at 65°C and 110°C, and cooled in a desiccator, soaked in oil for 24 hours, and their dry volume taken as before. The percentage of drying shrinkage was calculated on the wet volume.

(7) *Transverse Strength of the Raw Clay:*⁴ Ten bars, 6 by 1 by 1 inch, were made of each clay in its raw plastic state; in addition, a second portion was dried, pulverized, and carefully blended with 50% potters' flint, tempered, and then made into trial pieces similar to the above. All of these were dried at room temperature and finally at 110°C, cooled in a desiccator and broken transversely; the moduli of rupture were calculated by the usual formula.

(8) *Transverse Strength—Clay-Flint Mixture:* For this test the clays were first blunged and screened through 100-mesh, dried at 65°C, crushed through a 20-mesh screen, then blended with potters' flint in equal parts by weight. The mixture, after tempering, was thoroughly wedged and allowed to age for 24 hours. Twenty trials, 1 1/4 by 1 1/4 by 7 inches, were then molded, room dried and finally dried at 65° and 110°C. Ten of them were cooled in a desiccator followed by cross-breaking in a simple lever-type machine, using running shot to apply the load, 100 lbs. per minute. The remainder of the trials were fired in a commercial brick kiln to cone 8 and then broken in the same manner as the raw trials.

(9) *Volume Firing Shrinkage:* Forty trials, 1 1/4 by 1 1/4 by 1 1/4 inches, were prepared from each clay, their wet and dry volumes were taken, then ten of each were fired to cones 6, 8, 10, and 12 and their fired volumes determined, the per cent of shrinkage being calculated as per cent on the wet and dry basis.

(10) *Absorption and Apparent Porosity:* Sets of ten trials of each clay, 1 1/4 by 1 1/4 by 1 1/4 inches, were prepared for firing at cones 4, 6, 8, 10, 12, and 14, in an updraft muffle kiln fired with oil, the firing periods ranging from 30 to 46 hours. The trials were weighed at once when taken from the kiln, then placed in water with one face exposed for twenty-four hours, the water brought up to and held at boiling point for two hours, then allowed to cool, each trial wiped free of excess water, and weighed. The per cent absorption was calculated on the dry weight. The suspended weight in water was taken of the absorption trial pieces that the per cent apparent porosity could be calculated by Purdy's formula:

$$P = \frac{W' - D}{W - S} \times 100$$

Where P = per cent apparent porosity

W' = weight of the saturated test piece

D = " " " dry-fired " "

S = suspended weight of the fired test piece

⁴ It was found, with two or three exceptions, that the clays could not be dried free of checks; therefore the results were very misleading and are not published.

(11) *Apparent Specific Gravity:* The figures for the apparent specific gravity of the several clays were obtained from the dry and suspended weights of the fired volume shrinkage trials, using the formula and method of Purdy.⁹

$$\text{Apparent specific gravity} = \frac{\text{Dry weight}}{\text{Dry weight} - \text{susp. weight}}$$

(12) *Transverse Strength after Firing Clay-Flint Mixture:* Ten trial pieces of each clay were fired at cone 8 in a commercial firebrick kiln. Upon their return to the laboratory they were placed in a drying oven for twenty-four hours, cooled in a desiccator, then broken transversely, and their moduli of rupture determined by the usual formula.

(13) *Color after Glazing:* Disks of the plastic clay were jiggered in plaster molds $\frac{3}{16}$ inch deep and 10 inches in diameter. The disks were cut with a $3\frac{1}{8}$ -inch diameter-cutter into the desired trial pieces and dried away from dust, then fired at cones 4, 8, and 12. Five of the trials from each firing were glazed with a Standard borosilicate glaze kindly supplied by the Homer-Laughlin China Company of Newell, W. Va. The trials were then placed in saggars and fired in a muffle kiln to cone 2 in twelve hours.

(14) *Resistance to Crizzling:* The glazed trials of each clay used in the color study were placed in an electrically heated oven having a thermostatic control capable of maintaining a temperature within $\frac{1}{4}^{\circ}\text{C}$. The temperature was held at 225°C , being a spread of 210°C from that of the water used for quenching. After the oven and trials had been held at the desired temperature for one hour the trials were taken from the oven and immersed at once into running water at 15°C . When the trials were at the water temperature they were at once returned to the oven. This was repeated five times.

(15) *Oxidation:* For this test briquets, $1\frac{1}{4}$ by $1\frac{1}{4}$ by 2 inches, were made, dried, and then placed in the muffle of an oil-fired kiln and raised steadily in temperature to 750°C in five hours and then held constant at that temperature. Trials of each clay were drawn hourly, though in a few cases at half-hour intervals, until the clay requiring the longest period of oxidation showed no further traces of unoxidized material. The time required for oxidation has been plotted for comparison against the results obtained by Sortwell¹⁰ in a similar test on English and United States ball clays.

(16) *Fusion Test:* Cones were made of the several clays after washing. When dry the cones were calcined. The actual fusion determinations

⁹ R. C. Purdy, II, Geol. Surv., Bull., No. 9.

¹⁰ U. S. Bur. Stand., Tech. Paper, No. 227.

were made in a bottom-fired oxyacetylene furnace¹¹ as described by Gorton and Grover.

Results

TABLE I

CHEMICAL ANALYSIS

Generic Dept. No. Chemistry Dept. No.	2777 04/37	2632 04/37	2634* 05/37	2636* 07/37	2611 10/37	2616 11/37
Loss on ignition	11.60	12.085	12.02	2.16	17.51	12.45
Silica (SiO ₂)	51.02	51.285	54.31	65.14	54.49	45.03
Alumina (Al ₂ O ₃)	28.96	32.70	29.77	28.87	28.99	29.35
Titanium (TiO ₂)	1.02	0.68	0.78	1.05	0.75	0.82
Iron (Fe ₂ O ₃)	0.85	0.69	0.81	0.73	0.79	0.90
Lime (CaO)	0.78	0.72	0.68	Trace	1.08	0.58
Magnesia (MgO)	0.25	0.31	0.65	0.57	0.62	0.35
Alkali (Na ₂ O)	0.21	0.47	0.93	0.19	0.02	0.23
Total	100.45	100.53	100.22	100.38	100.20	100.20

* Unwashed

TABLE II

ELUTRIATION AND WASHING

No.	Per cent on 200-mesh	Per cent in No. 1 can	Per cent in No. 2 can	Per cent in No. 3 can	Per cent total sands	Per cent clay retention
2614	5.1	1.1	2.9	10.9	20.0	80.0
2615	5.3	2.5	5.4	8.4	21.6	78.4
2617	2.7	1.0	3.5	5.9	13.9	86.1
2619	5.2	2.0	5.1	8.4	20.7	79.3
2622	3.4	1.0	2.9	7.0	14.3	85.7
2624	5.5	0.8	4.5	8.5	19.3	80.7
2626	14.3	5.4	4.9	10.4	35.0	65.0
2627	3.2	0.0	3.5	10.0	16.7	83.3
2629	6.10	1.2	2.8	4.6	14.7	85.3
273	3.4	1.5	4.8	8.6	18.4	81.6
277	4.7	2.4	4.5	7.3	18.8	81.2
278	5.2	0.0	1.5	6.6	14.0	86.0
2720	42.1	1.5	1.5	1.5	46.9	53.1
2722	3.5	1.9	2.8	5.9	16.2	83.8
2723	2.9	8.2	4.3	8.0	23.4	76.6
2728	6.0	2.7	7.3	10.3	26.2	73.8
2734	4.8	5.7	7.2	11.1	28.8	71.2
2742	4.5	2.8	5.5	9.8	22.8	77.2
2767	3.0	2.1	1.5	2.7	11.3	88.7
2769	3.1	1.0	4.2	12.6	21.5	78.5
2770	6.1	0.0	3.4	10.6	20.7	79.3

TABLE III

HYDROGEN-ION CONCENTRATIONS

Clay no.		Clay no.	
2614	7.6	278	7.4
2615	7.0	2720	6.5
2617	6.6	2722	7.8
2619	6.6	2723	6.4
2622	6.9	2728	6.0
2624	7.3	2734	8.0
2626	7.2	2742	7.3
2627	7.9	2767	8.0
2629	7.7	2769	8.6
273	7.1	2770	6.2
277	7.4		

¹¹ *Jour. Amer. Ceram. Soc.*, **8** (11), 768-73 (1923).

TABLE IV
PER CENT WATER OF PLASTICITY

Clay no.	Per cent on wet basis	Per cent on dry basis	Clay no.	Per cent on wet basis	Per cent on dry basis	Clay no.	Per cent on wet basis	Per cent on dry basis
2614	25.5	34.2	2627	28.7	40.3	2733	28.9	40.7
2615	25.0	33.4	2628	24.6	32.6	2728	27.7	38.6
2617	24.8	32.9	273	26.3	35.7	2734	21.9	28.1
2619	23.3	27.5	277	27.9	38.7	2742	25.1	33.5
2622	25.5	34.3	278	29.3	38.1	2767	28.7	39.7
2624	27.9	38.6	2720	29.3	41.4	2769	24.5	32.5
2626	24.0	31.7	2722	25.2	49.1	2770	24.7	33.1

TABLE V
PER CENT PORE AND SHRINKAGE WATER

Clay no.	Per cent pore water	Per cent shrinkage water	Clay no.	Per cent pore water	Per cent shrinkage water
2614	10.62	17.00	278	15.10	26.40
2615	10.64	15.80	2726	19.00	22.40
2617	17.87	15.01	2732	11.46	22.34
2619	7.85	20.65	2723	17.35	23.40
2622	16.58	17.80	2728	18.65	21.75
2624	13.12	25.55	2734	12.50	15.51
2626	14.08	18.02	2742	14.89	18.91
2627	14.18	26.20	2767	18.53	21.67
2628	14.39	15.26	2769	16.75	15.20
273	15.94	19.82	2770	15.81	17.30
277	14.88	23.82			

TABLE VI
PER CENT DRYING SHRINKAGE

Volume shrinkage			Linear shrinkage			Volume shrinkage			Linear shrinkage		
No.	Wet basis	Dry basis	Wet basis	Dry basis		No.	Wet basis	Dry basis	Wet basis	Dry basis	
2614	25.1	33.5	9.18	10.11		278	33.5	50.6	12.72	14.62	
2615	23.4	30.5	8.50	9.38		2726	28.7	40.2	10.66	11.92	
2617	22.9	29.7	8.30	9.06		2722	29.4	41.6	10.98	12.29	
2619	27.8	38.6	10.39	11.49		2723	29.8	43.5	11.13	12.53	
2622	24.8	33.0	9.06	9.67		2728	24.5	40.0	10.62	11.92	
2624	31.8	40.7	11.98	13.62		2734	24.7	31.2	8.63	9.47	
2626	23.7	31.0	8.63	9.43		2742	35.4	33.9	8.31	10.22	
2627	32.3	40.9	12.63	14.44		2767	27.8	38.5	10.29	11.47	
2628	25.7	34.0	9.43	10.41		2769	22.1	28.4	7.99	8.99	
273	26.8	36.7	8.88	10.68		2770	24.2	31.9	8.82	9.67	
277	26.5	41.9	11.00	12.37							

TABLE VII
MODULUS OF RUPTURE OF UNFROZEN TRIALS

No.	60% clay 60% Sil	No.	60% clay 60% Sil	No.	60% clay 60% Sil
2614	748	2627	938	2723	862
2615	806	2628	757	2728	846
2617	679	273	722	2734	661
2619	652	277	737	2742	601
2622	754	278	795	2767	1008
2624	760	2726	439	2769	440
2626	511	2722	612	2770	668

TABLE VIII
PER CENT LINEAR FIRING SHRINKAGE, WET AND DRY BASIS

Clay no.	Case 4		Case 8		Case 10		Case 12	
	Wet basis	Dry basis	Wet basis	Dry basis	Wet basis	Dry basis	Wet basis	Dry basis
2614	7.35	8.41	7.71	8.75	8.07	9.11	8.19	9.15
2615	8.53	7.30	8.40	7.29	7.69	7.98	7.52	8.28
2617	8.59	9.25	8.70	9.39	8.94	9.64	9.43	10.05
2619	7.28	8.61	7.71	9.03	7.87	9.20	8.19	9.50
2622	8.27	9.32	8.74	9.70	9.06	9.97	9.67	10.52
2624	7.13	8.92	7.17	8.94	7.40	9.20	7.83	9.64
2626	4.61	5.45	4.70	5.61	4.94	5.82	5.13	6.00
2627	6.25	8.10	6.33	8.21	6.78	8.72	6.86	8.80
2629	7.12	8.21	7.64	8.72	7.71	8.77	8.78	9.81
263	7.91	9.11	7.91	9.11	8.30	9.47	8.70	9.86
277	6.02	7.45	6.33	7.81	7.17	8.69	8.11	9.67
278	8.75	7.87	7.69	9.11	7.17	9.17	7.26	9.89
2730	6.90	8.35	7.17	8.73	7.87	9.31	7.91	9.34
2732	5.42	6.80	5.65	7.03	6.21	7.65	6.78	8.29
2733	6.10	7.61	6.52	8.01	6.63	8.16	6.82	8.35
2738	7.64	9.05	8.15	9.58	8.34	9.75	8.54	9.97
2734	2.38	2.85	2.67	3.29	2.88	3.54	3.20	3.91
2742	7.61	8.07	7.38	8.35	7.52	8.58	7.62	8.58
2767	6.90	8.24	7.32	8.68	7.79	9.14	8.30	9.64
2769	7.60	8.22	8.07	8.77	8.19	8.86	8.19	8.86
2770	6.14	7.09	6.33	7.29	6.82	7.78	6.90	7.87

TABLE IX
PER CENT VOLUME FIRING SHRINKAGE ON WET AND DRY BASIS

No.	Case 4		Case 8		Case 10		Case 12	
	Wet basis	Dry basis	Wet basis	Dry basis	Wet basis	Dry basis	Wet basis	Dry basis
2614	20.5	27.4	21.4	28.6	22.3	29.8	22.6	29.2
2615	17.8	23.2	18.0	24.5	19.8	25.9	20.9	27.8
2617	23.4	30.4	23.9	30.9	24.5	31.8	25.7	32.3
2619	20.3	28.1	21.4	29.6	21.8	30.2	22.6	31.3
2622	22.8	30.2	24.0	32.0	24.8	32.0	26.3	35.0
2624	19.9	29.2	20.0	29.3	20.6	30.2	21.7	31.8
2626	13.2	17.3	13.6	17.8	14.1	18.5	14.6	19.1
2627	17.8	26.3	17.8	26.7	19.0	28.5	19.2	28.8
2629	19.9	30.7	21.2	28.5	21.4	28.7	24.1	32.4
273	21.9	29.9	21.9	29.9	22.9	31.2	23.9	32.6
277	17.0	24.1	17.8	25.3	20.0	28.4	22.4	31.9
278	18.9	25.5	18.8	26.9	20.0	29.1	20.5	29.9
2730	19.3	27.2	20.0	28.0	21.8	30.6	21.9	30.7
2732	15.4	21.8	16.0	22.6	17.5	24.8	18.0	27.0
2733	17.2	24.6	18.3	26.0	18.6	26.5	19.1	27.2
2734	21.2	29.7	22.5	31.5	23.0	32.2	23.5	32.0
2734	6.9	9.1	7.3	10.1	8.4	11.0	9.3	12.3
2742	19.6	26.2	20.3	27.2	20.9	28.6	20.9	28.6
2767	19.3	26.8	20.4	28.3	21.6	30.0	22.9	31.8
2769	21.1	27.1	22.3	28.7	22.6	29.0	22.6	29.1
2770	17.3	22.6	17.8	23.5	19.1	25.2	19.3	25.5

TABLE X
PER CENT ABRASION

Clay no.	Case 4	Case 8	Case 8	Case 10	Case 12	Case 14
2614	3.39	3.33	3.14	3.57	0.98	0.59
2615	5.76	5.70	5.68	4.15	3.03	0.39
2617	5.21	4.92	4.37	4.69	3.41	1.57

Clay No.	Case 4	Case 8	Case 8	Case 10	Case 12	Case 14
2619	3.87	3.35	2.78	2.48	1.27	0.82
2620	5.70	5.42	4.11	3.60	1.66	1.39
2624	3.21	2.42	1.95	1.65	1.00	1.62
2626	8.22	8.19	8.15	7.08	5.65	3.48
2627	2.54	2.43	2.30	2.12	1.57	1.05
2629	3.25	2.41	2.34	2.02	1.86	1.71
273	3.04	3.19	2.31	2.51	1.12	0.81
277	5.65	4.72	4.28	3.92	1.68	1.66
278	6.54	6.62	6.42	6.40	6.21	6.30
2720	6.75	8.47	7.81	7.61	5.40	1.56
2722	5.80	4.76	4.32	4.09	3.14	1.84
2723	5.46	5.00	4.51	4.10	2.41	1.41
2726	2.57	2.20	1.46	1.42	1.23	1.23
2734	8.12	8.66	7.60	7.80	5.63	1.97
2742	6.15	8.62	5.00	4.00	2.95	2.28
2767	3.44	2.05	1.96	1.84	1.63	1.29
2769	6.32	5.15	4.72	4.57	3.41	2.22
2770	6.22	5.80	3.95	4.64	2.85	1.61

TABLE XI
PER CENT APPARENT POROSITY

No.	Case 4	Case 8	Case 8	Case 10	Case 12	Case 14
2614	7.25	6.7	5.34	4.65	2.18	1.1
2615	12.43	8.97	7.64	7.13	4.68	6.88
2617	12.10	11.57	10.26	7.81	5.52	3.89
2619	8.22	7.02	6.26	4.22	2.65	1.00
2622	12.16	10.20	9.11	8.45	3.94	3.18
2624	7.0	5.63	4.30	4.30	4.20	4.13
2626	16.6	16.53	16.35	14.20	12.66	9.62
2627	3.62	3.44	3.00	4.63	3.62	2.76
2629	7.2	4.84	4.85	4.41	3.70	2.86
273	7.06	6.15	5.40	4.21	2.75	1.75
277	11.93	8.29	7.85	6.2	2.34	2.68
278	1.21	1.10	1.04	0.87	0.51	0.50
2720	19.9	17.70	16.60	15.5	11.80	3.40
2722	11.63	9.10	9.11	9.65	5.65	4.10
2723	11.63	10.86	9.61	8.21	5.52	3.18
2726	6.31	4.70	3.59	3.19	2.45	2.24
2734	16.33	16.19	15.7	13.7	11.42	4.15
2742	13.30	12.20	11.17	9.02	6.85	6.03
2767	7.40	3.15	4.26	4.02	3.30	3.79
2769	14.7	12.14	11.36	11.04	8.74	7.20
2770	13.23	12.50	8.85	7.85	6.70	4.80

TABLE XII
APPARENT SPECIFIC GRAVITY

No.	Case 4	Case 8	Case 8	Case 10	Case 12
2614	2.16	2.21	2.34	2.50	2.37
2615	2.11	2.15	2.13	2.14	2.16
2617	2.20	2.25	2.27	2.24	2.22
2619	2.27	2.27	2.34	2.28	2.23
2622	2.21	2.21	2.24	2.26	2.26
2624	2.29	2.37	2.29	2.32	2.36
2626	2.02	2.08	2.01	2.05	2.09
2627	2.24	2.20	2.27	2.28	2.21
2629	2.22	2.23	2.26	2.25	2.23
273	2.24	2.22	2.24	2.28	2.29
277	2.11	2.24	2.20	2.14	2.27
278	2.40	2.47	2.44	2.41	2.43
2720	2.03	2.13	2.11	2.07	2.17
2722	2.13	2.25	2.22	2.21	2.22
2723	2.19	2.18	2.19	2.22	2.21

TABLE XII (Continued)

No.	Cone 4	Cone 8	Cone 9	Cone 10	Cone 12
2728	2.34	2.40	2.41	2.09	2.28
2734	1.87	1.84	1.99	2.03	2.03
2742	2.31	2.27	2.26	2.21	2.24
2767	2.18	2.29	2.27	2.27	2.28
2789	2.14	2.27	2.28	2.23	2.27
2770	2.19	2.25	2.27	2.24	2.20

TABLE XIII
MODULUS OF RUPTURE OF FIRED TRIALS, CONE 8
(50% clay—50% flint)

No.	Lb.	No.	Lb.	No.	Lb.
2614	2296.0	2627	1715.6	2723	2112.0
2615	2121.6	2629	2199.3	2738	2014.0
2617	2303.0	271	2704.3	2734	1760.0
2619	1961.5	277	2017.0	2742	2433.3
2622	2201.8	278	2307.3	2767	2145.0
2624	2861.0	2780	1751.6	2768	1841.6
2626	2402.6	2722	2559.0	2770	2328.3

TABLE XIV
COLOR AFTER GLAZING

No.	Cone 4	Cone 8	Cone 12
2614	Light cream; many small black specks	A darker shade of cream; specks more pronounced	A light bluestone; specks more pronounced
2615	A clear light cream; specks just visible	A deeper shade of cream; many light brown specks	Practically the same as cone 8 trials
2617	A creamy white; a few dark specks	Same shade of white; specks numerous	Slightly darker shade; specks more pronounced
2619	A deep cream; numerous small specks	Slightly deeper shade; specks numerous	Bluestoned throughout; specks quite black
2622	Nearly white; specks can be seen only with a glass	A light cream white; few small yellowish specks	Practically the same as cone 8 trials
2624	Nearly white; specks seen only by use of a glass	Practically the same as cone 4 trials	Bluestoned throughout; a glass needed to see specks
2626	A light cream; a few specks just visible	Same shade as cone 4; specks more pronounced	A deep cream; numerous yellowish specks
2627	A medium cream; numerous specks showing	Practically the same as cone 4; specks are darker	Trials are starting to bluestone; specks same as cone 8
2629	A dark cream or ivory; a few specks showing	A much darker shade; specks quite pronounced	Bluestoned throughout; specks same as cone 8
273	A clear light cream; no specks	A much deeper shade; yellowish specks	Same as cone 8
277	A light ivory or cream; no specks	About the same shade; a few specks showing	A deep ivory and signs of bluestoning; a very few specks
278	A yellowish white with many specks	A light bluestoning; many specks	A deep bluestoning; many black specks

No.	Cone 4	Cone 8	Cone 12
2720	Light creamy white few specks	Slightly lighter shade specks more pronounced	Shade same as cone 4 though specks show more plainly
2722	An ivory tint, badly specked	Same as cone 4 trials	A darker shade, otherwise the same as cones 4 and 8 trials
2723	A clear light cream, no specks	Just a shade darker a few odd specks	Bluestoned a few specks showing
2728	A light creamy white no specks	A darker cream color only an odd speck	Bluestoned, an odd speck or so
2734	A very deep clear cream no specks	A slightly lighter shade, yellowish specks show- ing	A deep yellowish cream, specks same as cone 8 trials
2742	Nearly white, no specks	A slight cream tint and a few specks	Practically the same as cone 8 trials
2757	A light cream with light brown specks	A lighter shade though starting to bluestone	Bluestoned throughout, clear of specks
2769	A creamy white, free of specks	A deeper shade and specks showing	Practically the same as cone 8
2770	Nearly white free of specks	Same in shade, few specks showing	Shade only slightly changed specks same as cone 8

Best White or nearly White at

Cone 4	Cone 8	Cone 12
2611	2611	2622
2622	2622	2742
2624	2624	2770
273	2742	
2728	2769	
2742		
2769		
2770		

Best Light Cream or Ivory at

Cone 4	Cone 8	Cone 12
2615	2619	2720
2619	2627	
2624	2627	
2627	271	
277	2720	
2720	2722	
2722	2723	
2723		
2767		

Best Deep Cream or Ivory at

Cone 4	Cone 8	Cone 12
2734	2728	277
	2734	2722
	2769	2734
		2769

Bluestoned at

Cone 8	Cone 12	Cone 17
278	2614	277 (slight)
2767	2619	278
	2624	2723
	2627 (slight)	2726
	2629	2767

Clays Speck Free at

Cone 4	Cone 4	Cone 8	Cone 12
2622	2734	None	None
2624	2742		
273	2769		
2723	2770		
2728			

Clays Lowest in Specks at

Cone 4	Cone 8	Cone 8	Cone 12
2615	2622	2767	2622
2620	2624	2770	2624
2629	277		277
2720	2723		2723
	2728		2728
	2742		2742
			2767
			2770

TABLE XV

RESISTANCE TO CRAZING

No.	Case 4	Case 8	Case 19
	20% S.C. 80% N.C.	100% N.C.	100% S.C. 40% N.C.
2014	99% S.C. 60% N.C.	100% N.C.	20% S.C. 80% N.C.
2015	100% S.C.	50% S.C. 50% N.C.	20% S.C. 80% N.C.
2016	20% S.C. 80% N.C.	50% S.C. 50% N.C.	100% N.C.
2022	100% N.C.	40% C 60% N.C.	100% N.C.
2024	100% N.C.	100% N.C.	100% N.C.
2026	40% S.C. 60% N.C.	100% N.C.	100% N.C.
2027	10% S.C. 80% N.C.	100% N.C.	100% N.C.
2029	100% N.C.	50% S.C. 50% N.C.	100% N.C.
2073	100% N.C.	80% S.C. 20% N.C.	60% S.C. 40% N.C.
2077	80% S.C. 20% N.C.	100% N.C.	100% N.C.
2078	100% S.C.	100% N.C.	100% N.C.
2120	100% B.C.	100% C.	50% S.C. 50% N.C.
2122	20% C. 80% N.C.	60% S.C. 40% N.C.	60% S.C. 40% N.C.
2125	15% S.C. 85% N.C.	100% N.C.	100% N.C.
2126	40% C. 60% N.C.	100% N.C.	30% S.C. 20% N.C.
2134	100% S.C.	60% S.C. 45% N.C.	75% S.C. 25% N.C.
2142	100% N.C.	40% S.C. 60% N.C.	80% S.C. 20% N.C.
2167	60% S.C. 40% N.C.	100% N.C.	25% S.C. 75% N.C.
2169	30% C. 60% N.C.	100% N.C.	100% S.C.
2170	40% S.C. 60% N.C.	15% C. 25% N.C.	100% C.

Key

C Normal crazing
S.C. Slight crazing
B.C. Badly crazed
N.C. Non crazing

TABLE XVI
Time Required for Oxidation at 750°C

Lithology No.	Hours required to oxidize at 750°C	Remarks
2614	2	Very little oxidation necessary
2615	11	Oxidation required practically nil
2617	3 1/2	Easily oxidized
2619	7	Fairly difficult to oxidize
2622	4	Easily oxidized
2624	8	Quite difficult to oxidize
2626	7	Oxidation required practically nil
2637	8	Difficult to oxidize
2639	4	Only slightly difficult to oxidize
273	3	Slight oxidation only required
277	14	Very difficult to oxidize
278	5	Fairly easy to oxidize
2730	7	Very easy to oxidize
2732	4	Fairly easy to oxidize
2733	22	Very difficult to oxidize
2738	4	Fairly easy to oxidize
2734	7 1/2	Slight oxidation only required
2742	5	Fairly easy to oxidize
2767	15	Very difficult to oxidize
2769	4	Readily oxidized
2771	7	Fairly easy to oxidize

TABLE XVII
Fusion Point
(°C. R.)

No.	Comp.	%	No.	Comp.	%	No.	Comp.	%
2614	32	708*	2627	40 +	1028	2723	31 +	1045
2615	34	1685	2629	31	1085	2724	32	1705
2617	32 +	7 3/2	273	31 +	1685	2744	27	1020
2619	31	1625	274	31	1685	2742	32 +	1712
2622	33	720	278	31	1685	2767	31	1685
2624	41 +	1695	2736	72 +	1112	2769	32	1705
2626	30	670	2728	31	660	2771	32 +	1512

* Revised scale, U. S. Bureau of Standards

Note: All clays washed through 100 mesh

General Geological Section Southern Saskatchewan

That the geological position of the Saskatchewan ball clays may be noted the following outline or general section* is given

Glacial	Surface	
Cypress Hills	Oligocene	
Reynoldsburg	Port Union	Tertiary
Whitemud	(Recent)	
Estevan		
Peace, Potholes	Montana	Cretaceous
Belly River		

*Davis, 1916, Clay Resources of Southern Saskatchewan.

Geological Sections of Dikes

	Fe	ln		Fe	ln
2636					
Glacial and Ravenscrag	30-40	0	2639, dark gray gritty clay (black stems)	5	0
Clayish lignite, iron-stained	2	0	Yellowish to gray shaly clay	4	0
2634, light gray plastic clay	0	1	Lead gray sandy clays (Estevan)		
White plastic clay	10	0			
Iron streak					
Unknown					
2635			2638		
2637			Glacial and Ravenscrag	0-30	0
Glacial and Ravenscrag	14	0	2723, grayish purple plastic	10	0
Lignite	1	3	White clay, iron-stained	6	0
2617, purple to yellowish gray plastic	17	0	Grayish sandy clay, black stems	6	0
(iron stain and concretions)			Dark rusty shale	2	1
2613, white plastic clay (fine concretions)	10	0	White sandy clay	12	0
Lead gray sandy clays (Estevan)			Unknown		
2618			2724*		
Glacial and Ravenscrag	25	0	Alluvial and Ravenscrag	3-6	1
Lignite	2	0	Lignite clay	2	0
Dark chocolate clay	3	0	Purplish to dark clay	1	0
2615, light gray purplish tang plastic clay (iron-stained)	4	0	Light gray nearly white clay	1	0
Gray clay fine iron concretions	5	0	2774, blue plastic clay, gritty	2	0
Lead gray sandy clays (Estevan)			Coarse sandy blue clay	4	0
2637			Unknown		
Glacial and Ravenscrag	15	0	* Taken from a test pit in valley, clay carries under deep cover in valley sides		
Lignite	0	0	2725*		
2633, purple plastic clay (iron concretions)	8	0	Glacial and Ravenscrag	10-30	0
Silty shale, light brown	3	0	273 gray clay, purplish tint	4	1
Lignite	1	0	Unknown		
Dark gray gritty clay	4	0	* From drift mine		
Gray sandy clay	8	0	277		
Unknown			278		
2634*			Glacial and Ravenscrag	30	0
Glacial and Ravenscrag	4-20	0	Lignite	2	0
2638, purple plastic, grayish	4	0	Dark gray clay	2	0
Unknown			Light gray clay	2	0
*From drift mine			Iron stain (discarded)	0	10
2638			Gray clay	5	0
2637			(Iron stain near base)		
Glacial and Ravenscrag	30	0	Dark nearly black clay	1	0
Lignite	2	0	Gray gray clay	2	1
2637, light gray gritty clay	0	0	Gray to dark chocolate clay	2	0
2636, light gray gritty clay	3	0	Chocolate to nearly black clay	4	0
White sandy clay coarse grain	14	0	2710		
Unknown			2712		
2639			2713		
Glacial and Ravenscrag	25	0	Glacial and Ravenscrag	0-30	0
Sandy gray shale	12	0	2723, black plastic clay	2	0
Lignite	1	0	2722, gray clay purplish tint	4	0
Yellowish shaly clay	4	0	White plastic, many iron concretions	4	0
			2720, white sandy clay	20	0
			Lead gray sandy clays (Estevan)	2	

	Pt.	Ln.		Pt.	Ln.
2766*			2769, grayish with purple tint (Nodular iron concretions)	6	0
Glacial and Ravenscrag	3-40	3	Yellowish iron-stained gray	7	0
Yellowish shale (Ravenscrag)	6	0	White plastic, fine-iron concretions	10	0
Lignite	0	6	Lead gray sandy beds (Estevan)	*	
2842, bluish clay, dries gray	4	0			
Unknown					
* From a test pit					
2827			2742*		
Glacial and Ravenscrag	30	0	Glacial and Ravenscrag	5-40	0
Lignite	2	0	Yellowish shale (Ravenscrag)	6	0
Purplish plastic clay	2	0	Lignite	3	0
Iron seams	0	0	2742, bluish clay dries gray	4	0
Grayish plastic clay	9	0	Unknown		
Black plastic clay	2	0			
Gray to dark chocolate clay	2	0	* From a test pit		
Dark chocolate to black clay	1	0	2767		
Dark clay	3	0	Glacial and Ravenscrag	30	0
Unknown			Lignite	2	0
			Purplish plastic clay	2	0
2766			Iron seams	0	10
2770			Grayish plastic clay	8	0
Glacial and Ravenscrag	15	0	Black plastic clay	2	0
Lignite	1	0	Gray to dark chocolate clay	2	0
2770 Dark chocolate to purple	1	0	Dark chocolate to black clay	1	0
Lighter shade	2	0	Dark clay	3	0
(Nodular iron concretions)			Unknown		

Summary

The ball clays, the physical properties of which have been here described differ both from the English and American ball clays in several respects, though their plasticity and working properties are the equivalent of the best clays of this type.

The water of plasticity of the Saskatchewan clays averages about 25% on the wet basis. This figure is somewhat lower than the normal for either American or English clays, it no doubt explains in a measure the lower drying shrinkage of the Saskatchewan clays and indicates the existence of a different structure.

The remarkably high strength in the raw state of the Saskatchewan clays is noteworthy. On comparison with figures given by Parmelee and McVay¹² it is to be observed that the three Saskatchewan clays of highest strength exceed the three strongest American and English clays by 26 + %. Further, in a similar comparison with figures by Sortwell¹³ the difference in favor of the Saskatchewan clays is 74 + %. Therefore, in cases where high bonding power strength in the raw or bisque state is desirable, the Saskatchewan clays are of much interest.

¹² *Trans Amer Ceram Soc.*, 10 (8), 398-428 (1927).

¹³ See reference 10, p. 5.

On the other hand they are more inclined to crack in drying than the standard clays of this type, a fact to be taken into consideration in determining the amount it is safe to use in a given body.

From reliable sources the firing shrinkage of ball clays in actual use at cone 4 is about 20%. The Saskatchewan clays here reported on as

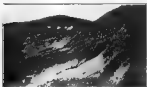


FIG. 3

a rule, show a shrinkage lower than the above figure at the same temperature. This may be accounted for in part by different firing conditions.

The trend of the shrinkage curves of some of the Saskatchewan clays is quite different both from the English and American ball clays, the latter show at cone 8 a drop in absorption to about 5%, while a

number of the Saskatchewan clays remain somewhat more open at this cone.

Through a study of the volume shrinkage porosity curves it is noticeable that the Saskatchewan clays have on the whole a lower shrinkage than either the American or English ball clays, the rate of change being more nearly that of the English clays. On the other hand the Saskatchewan clays, with one exception, show a higher porosity than the English clays between cones 6 and 12, and, in addition, there is a slight continuous change from cone to cone in the Saskatchewan clays where the English clays remain constant. In comparison with Tennessee ball clays the Saskatchewan clays show slightly lower porosity changes between cones 6 and 12, and materially less than those of the Kentucky clays.

It is to be noted among the Saskatchewan clays that eight of them are white or nearly white at cone 4 and of these three remain white at cone 8. Nine are light cream at cone 4 and of these seven remain of the

same shade at cone 8. Thus, where a white body is desirable some of the Saskatchewan clays are of interest, and especially so in that section were requiring maximum strength in the raw. One difficulty is met with, however, through the presence of more or less dark specks due to some iron-bearing material. While traces were found in all samples, five of them



FIG. 4

have proven sufficiently free of speck to permit of their use in large quantities in the U. S. whiteware industry during the past three years. Further study with reference to the removal of the objectionable specks in the Saskatchewan clays is to be recommended.

The chemical analyses of the Saskatchewan clays indicate that they carry more free silica than the average English and American ball clays. Generally speaking the average pottery ball clay in the dry state fluctuates around 35% alumina content. The present clays, with one exception, carry from 28.8 to 29.8% of alumina.

Though the fusion point of ball clays may be of little interest to the manufacturer of whiteware, they were obtained in the present work for each of the clays and the findings have proved of interest in that eight of them have a P.C.E. of cone 32 or more. This quality, in connection with their high strength in the raw state, makes them worthy of study as bond clays for various lines of refractories.

The time required for the oxidation of ball clays is not normally of much importance, since in the manufacture of whiteware other body constituents are nearly always introduced, which open up the structure. Of the clays tested, however, 2723 is the only one which might lead to manufacturing difficulties in the firing of the ware.

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